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Frivik

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(54) **QUALITY SENSOR APPARATUS**

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(2013.01); **G01N 25/00** (2013.01); **G01N 27/00**

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(58) **Field of Classification Search**

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USPC **73/1.01**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,114,859 A * 5/1992 Kagenow 436/50
5,208,147 A * 5/1993 Kagenow et al. 435/14
7,122,152 B2 * 10/2006 Lewis et al. 422/50
2002/0090738 A1 * 7/2002 Cozzette et al. 436/518

* cited by examiner

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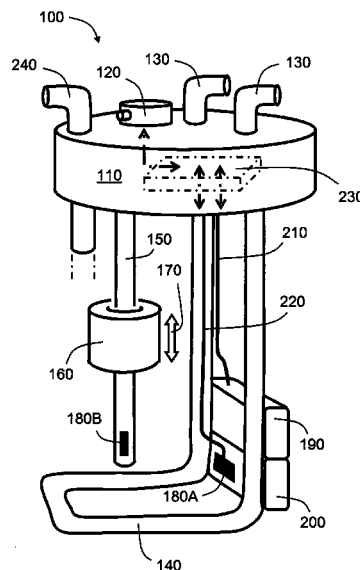
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(57) **ABSTRACT**

An apparatus (100) for measuring quality of a urea solution is operated with at least a portion of the apparatus inserted into the urea solution. The apparatus (100) includes a configuration of sensors (180, 190, 200) for measuring mechanical and electrical properties within a volume of the urea solution, the measurements of mechanical and electrical properties being mutually differently influenced by components present in the urea solution. A data processing arrangement (230) of the apparatus (100) is operable to process the measurements of mechanical and electrical properties for generating output data (120) indicative of a quality of the urea solution. The apparatus (100) is also capable of being adapted to measure qualities of other types of solution.

14 Claims, 7 Drawing Sheets



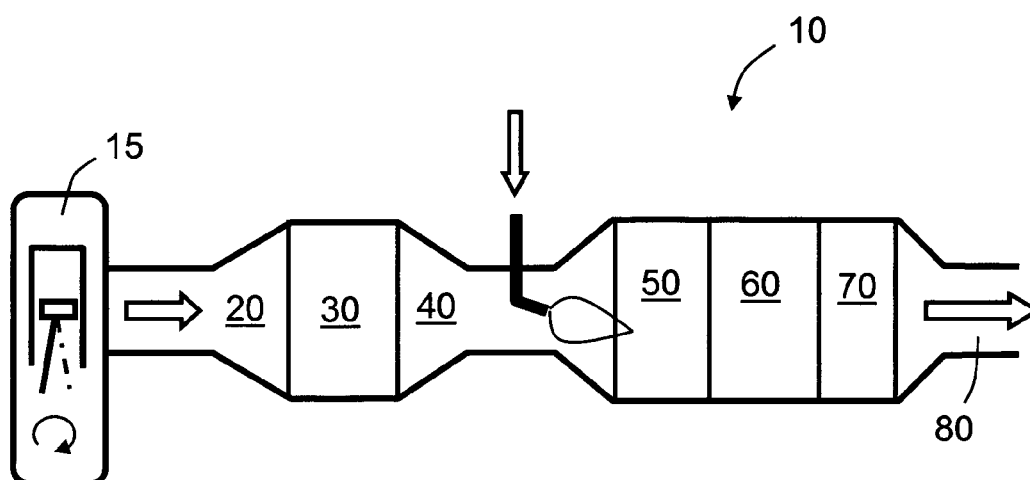


FIG. 1

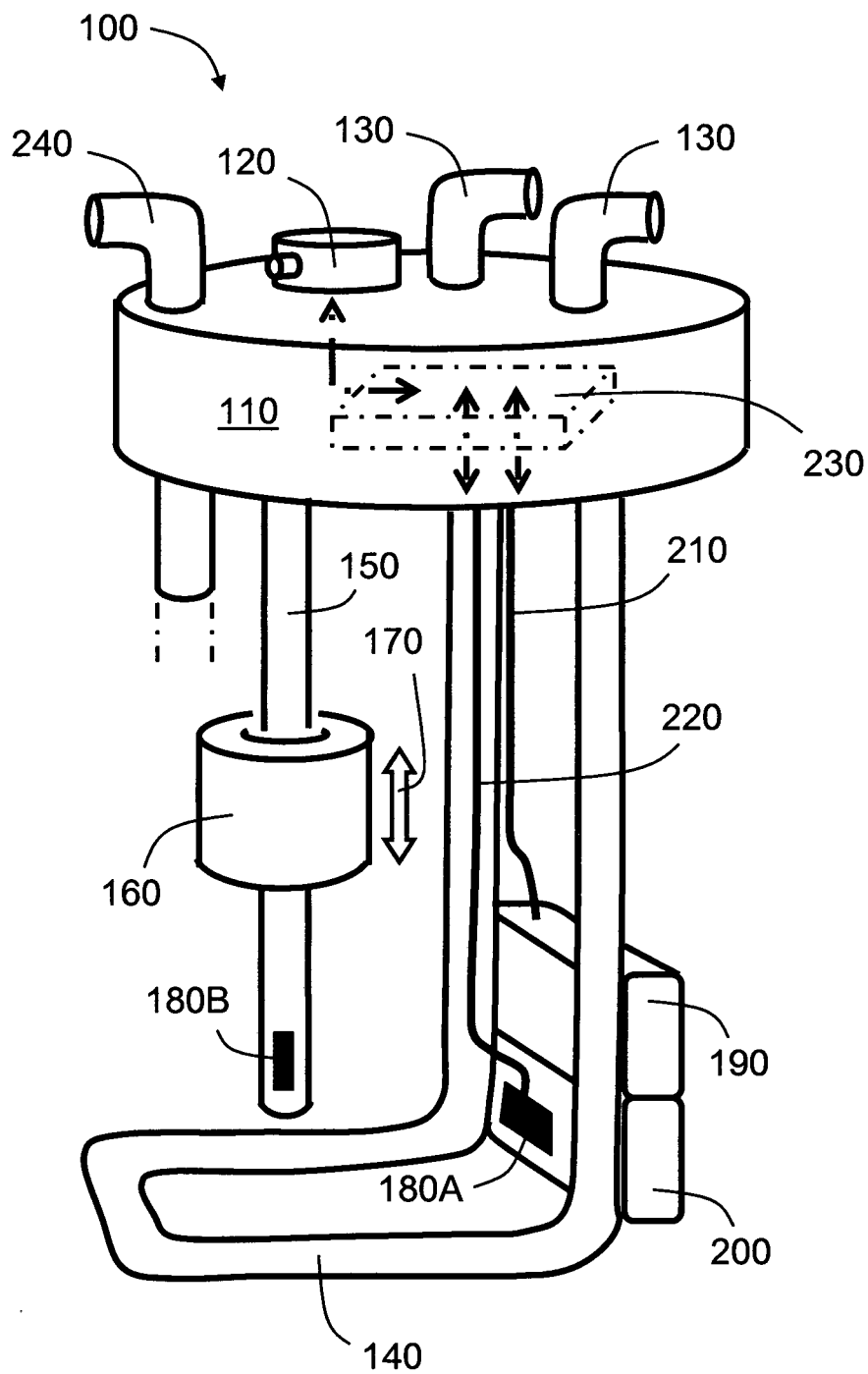


FIG. 2A

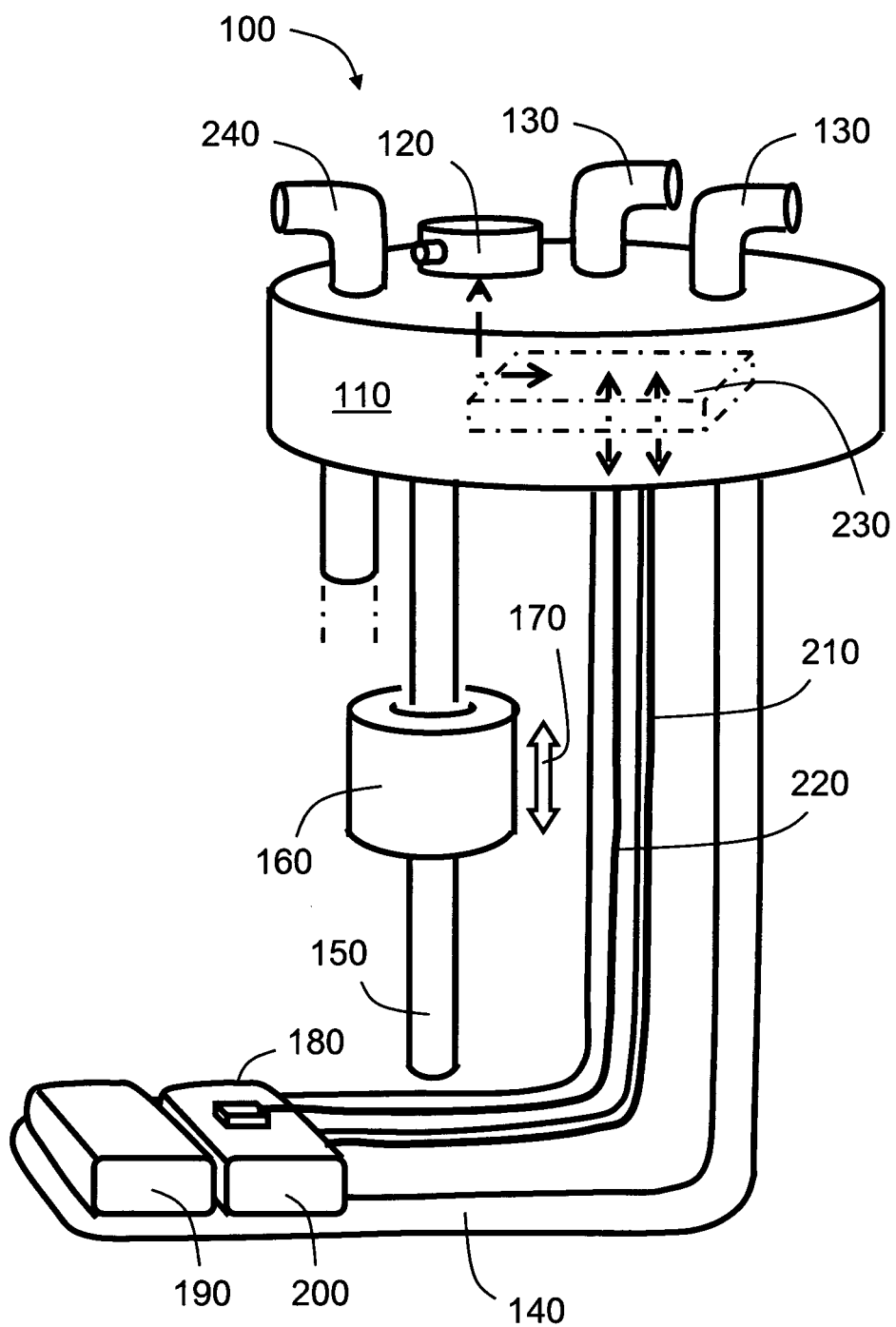


FIG. 2B

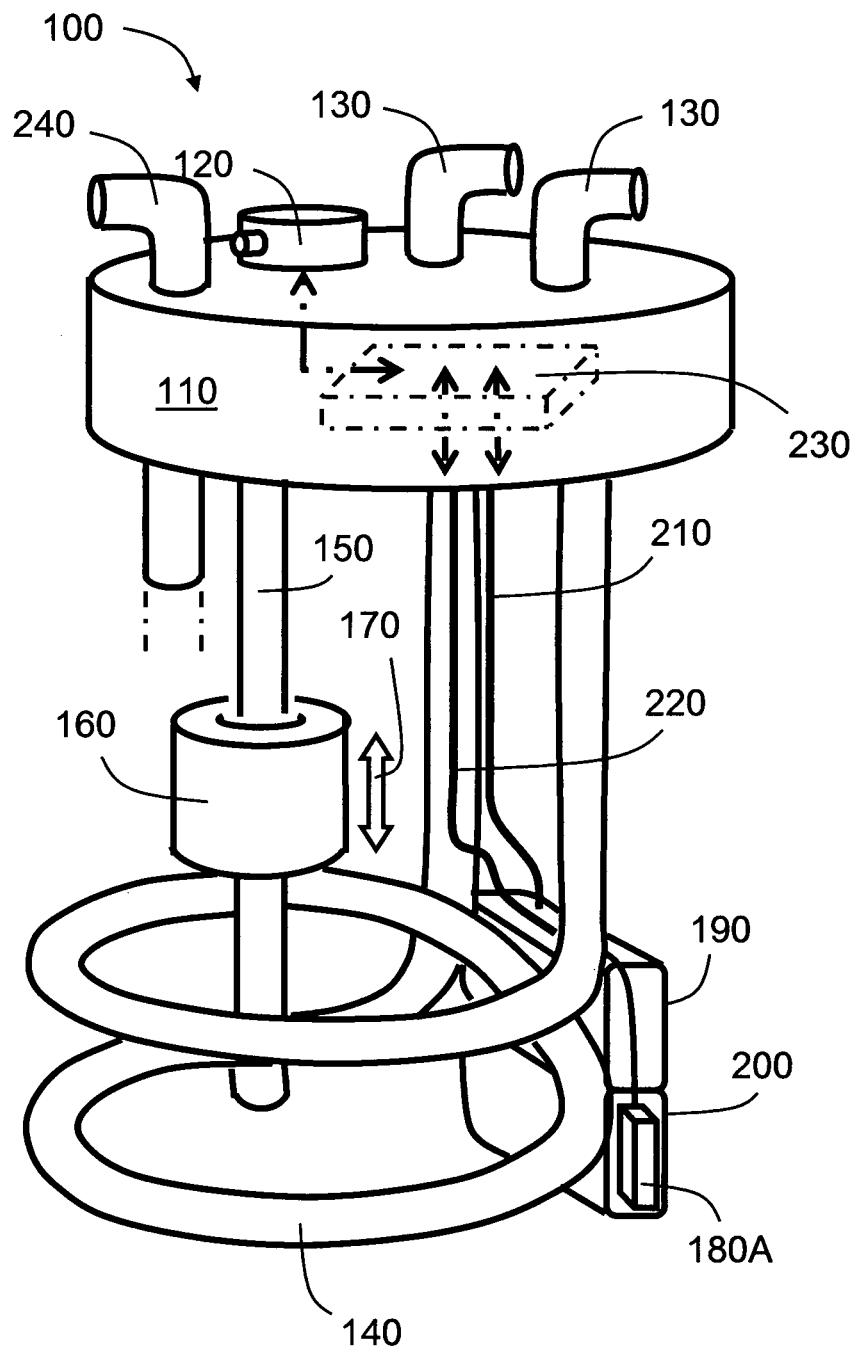


FIG. 2C

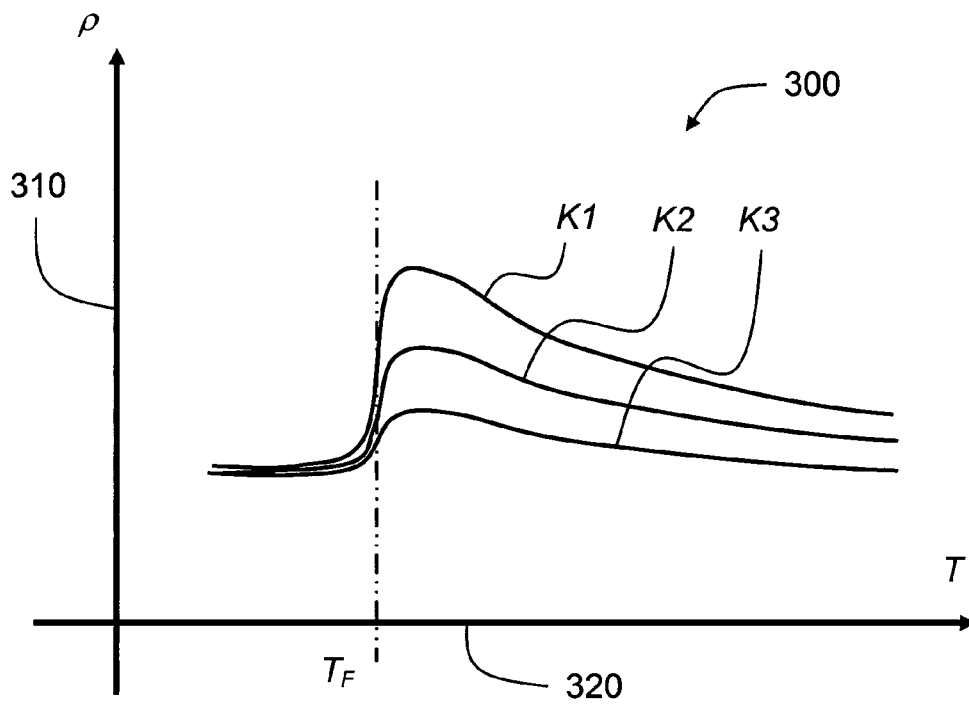


FIG. 3

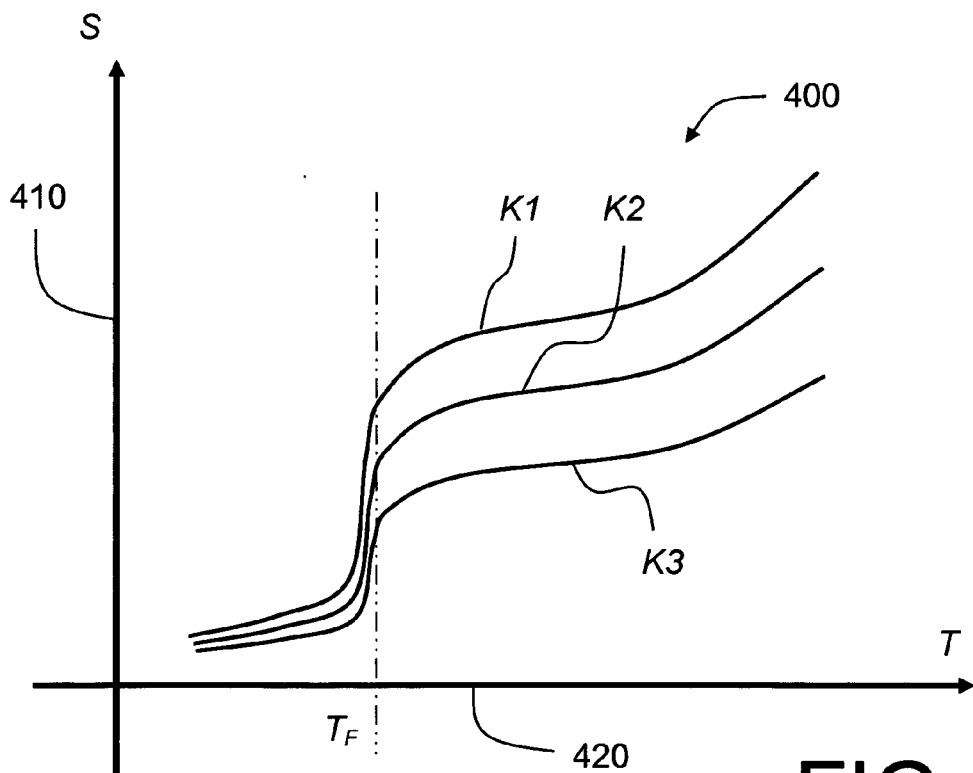


FIG. 4

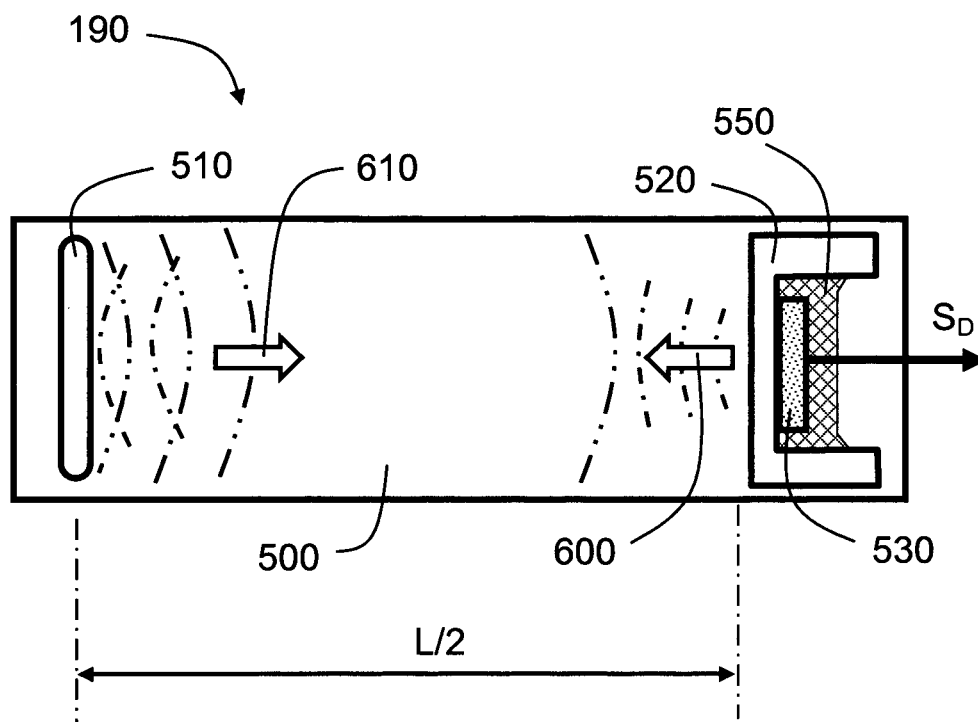


FIG. 5

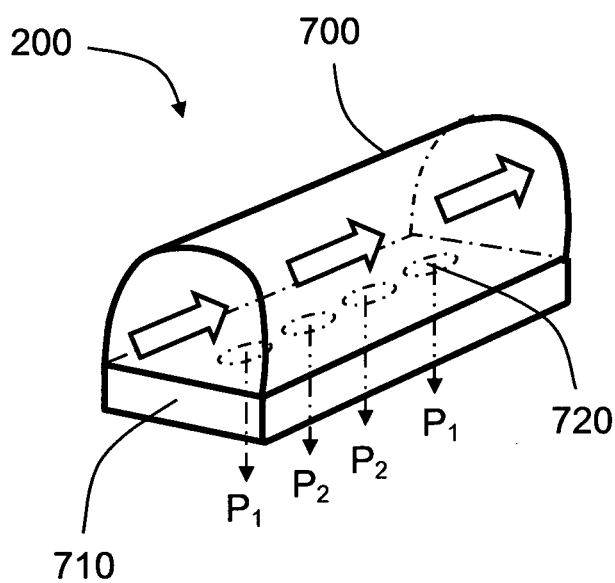


FIG. 6

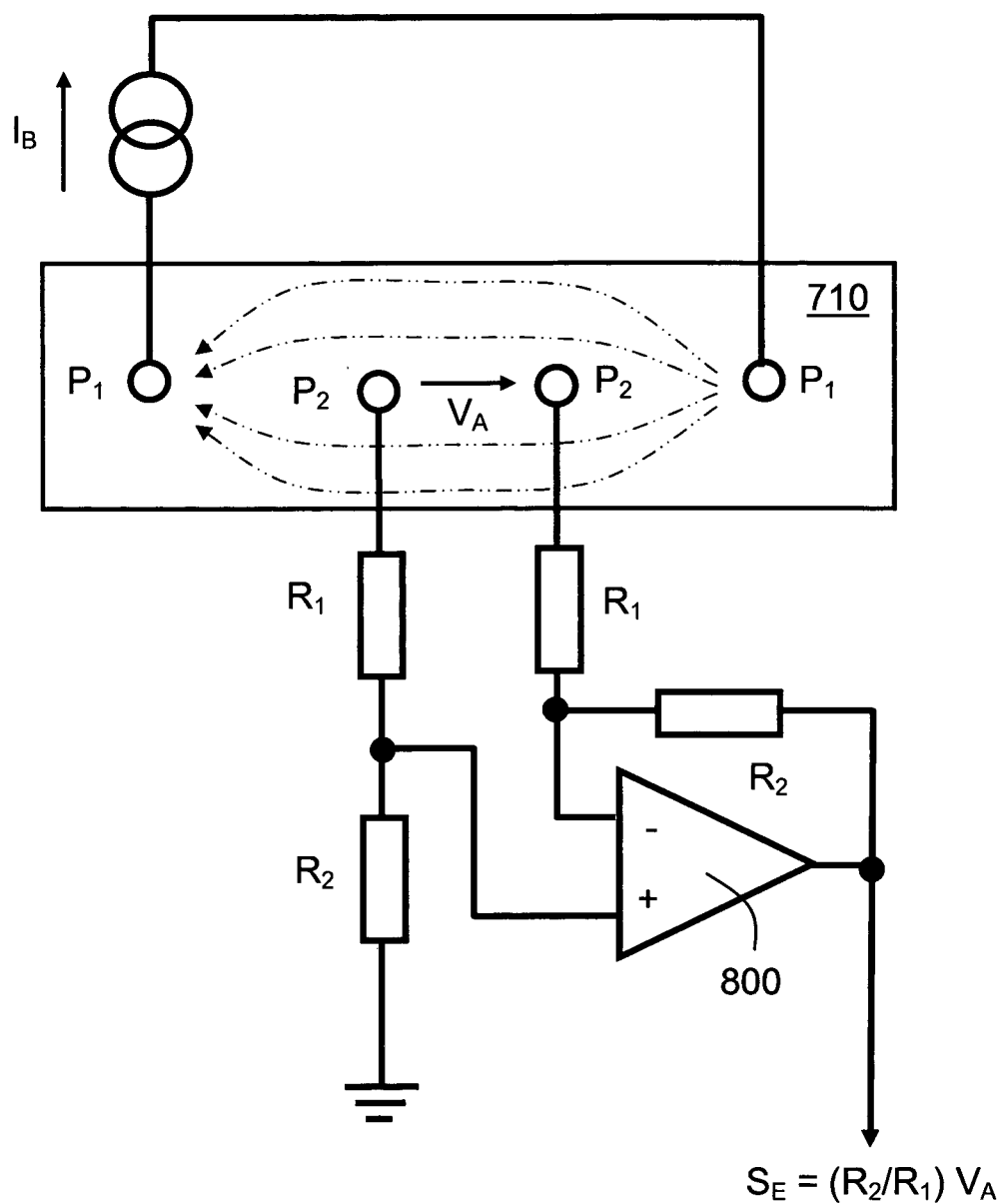


FIG. 7

QUALITY SENSOR APPARATUS

FIELD OF THE INVENTION

The present invention relates to quality sensor apparatus for vehicles, for example on-road and off-road vehicles, as well as for industrial and marine installations including combustion engines, wherein the apparatus is operable to monitor the quality of urea solution (for example AdBlue, "Adblue", DEF) to exhaust treatment systems of such vehicles and installations. Moreover, the invention concerns methods of operating such quality sensor apparatus. Furthermore, the invention relates to vehicles, industrial facilities and marine facilities including the quality sensor apparatus.

BACKGROUND OF THE INVENTION

Contemporary combustion engines beneficially operate with combustion in their one or more combustion chambers occurring at a high combustion temperature for achieving more efficient engine operation. However, engine operation at high combustion temperatures has associated therewith generation of soot and nitrogen oxide exhaust products, for example nitrous oxides (NOx). Soot and nitrogen oxide exhaust products are hazardous materials when ejected into the environment. For reducing concentrations of exhaust pollutants to within limits defined by legislation, for example contemporary European legislation pertaining to exhaust emissions, vehicle manufacturers conventionally employ Selective Catalytic Reduction (SCR) and/or Exhaust Gas Recirculation (EGR) in their vehicles. SCR is effective for absorbing nitrous oxides whereas EGR ensures more complete oxidation of nitrogen oxides present in exhaust gases.

SCR operation is improved by using chemical agents which are transported and/or stored on vehicles, marine facilities and industrial facilities. For example, "AdBlue" and "DEF" are trade names for a chemical agent corresponding substantially to aqueous urea solution 32.5%. This solution is injected into exhaust gases of modern diesel engines during a post-combustion process for treating engine exhaust gases for reducing a proportion of harmful nitrous oxide (NOx) present in these gases. AdBlue, DEF, "Adblue" is only ever used in conjunction with an SCR. Moreover, vehicles which are equipped with an SCR will carry an AdBlue, DEF or "Adblue" storage tank in addition to a fuel tank. In operation, AdBlue, DEF, or "Adblue" is transferred from the storage tank and injected under pressure into exhaust gases where a series of chemical reactions occur as outlined in Table 1 below.

In FIG. 1, an exhaust system for a combustion engine 15 is indicated generally by 10. The system 10 includes in sequence an inlet 20 for receiving combustion gases from the engine 15, an oxidation catalyst 30, an AdBlue injection region 40, an hydrolysis catalyst 50, an SCR catalyst 60, an oxidation catalyst 70 and finally an outlet 80.

TABLE 1

Region	Reaction
Oxidation catalyst 30	$2\text{NO} + \text{O}_2 = 2\text{NO}_2$
	$2\text{CO} + \text{O}_2 = 2\text{CO}_2$
	$4\text{HC} + 3\text{O}_2 = 2\text{CO}_2 + 2\text{H}_2\text{O}$
Hydrolysis catalyst 50	$\text{CO}(\text{NH}_2)_2 + \text{H}_2\text{O} = 2\text{NH}_3 + \text{CO}_2$
	$8\text{NH}_3 + 6\text{NO}_2 + 7\text{N}_2 + 12\text{H}_2\text{O}$
	$4\text{NH}_3 + 4\text{NO} = \text{O}_2 + 4\text{N}_2 + 6\text{H}_2\text{O}$
SCR catalyst 60	$2\text{NH}_3 + \text{NO} + \text{NO}_2 = 2\text{N}_2 + 3\text{H}_2\text{O}$
	$4\text{NH}_3 + 3\text{O}_2 = 2\text{N}_2 + 6\text{H}_2\text{O}$
Oxidation catalyst 70	

Essentially, the process occurring in the exhaust system 10 involves an AdBlue mixture being passed onto a super-heated porous ceramic head of the SCR catalyst 60 whereat the de-ionised water evaporates and remaining urea of the injected AdBlue is passed on as a reagent which is operable to break nitrous oxide components (NOx) into mostly Nitrogen and water. Any contaminants present in the AdBlue will collect on the SCR catalyst 60, eventually causing it to clog and fail. It is therefore imperative that the AdBlue remains free from impurities through all stages of production, storage and dispensing.

Detection of ingredients in AdBlue, DEF or "Adblue" is highly desirable; detection of such ingredients is to be understood to be a quality measurement, not merely a measurement of urea concentration which is something different. Agricultural grades of urea are designated for use in agriculture, for example to improve soil quality, whereas industrial grades of urea, for example Adblue, DEF, are adapted for use in road vehicles, for example trucks and buses. When agricultural urea is cheaper on account of more contaminants therein in comparison to industrial AdBlue, there is a temptation for users to employ agricultural AdBlue in trucks and buses for exhaust gas treatment during road use in breach of legal regulations; impurities in agricultural grades of urea can potentially poison catalysts in exhaust systems as well as risk creating airborne pollution including, for example, heavy metals. Moreover, there is also a potential risk that agricultural urea or industrial AdBlue, DEF is contaminated by extraneous material on account of conditions of its storage, for example in unclean tanks which have previously employed to store other materials, for example insecticides.

Another risk is an unintentional confusion by personnel of different tanks available on a vehicle, wherein Diesel fuel, wind screen washer liquid and similar is filled into the Adblue, DEF tank by accident. Another risk is that personnel try to substitute Adblue, DEF with other materials, for example a saline solution, in Adblue, DEF tanks of vehicles to save money. Many farmers face extreme economic pressures which can result in them being attempted to save wherever feasible

Unwanted contamination in Adblue, DEF can have other consequences, for example resulting in a catastrophic event such as a complete SCR failure. Attempting to operate vehicles with defective SCR can represent a criminal offence. AdBlue, DEF is very susceptible to contamination from both foreign matter and incorrect material selection. A main influence concerns the de-ionised water element of the solution which draws ions from materials which it comes into contact with; this changes the chemical composition of the AdBlue, DEF and causes salts to form which in turn clog the ceramic head on the SCR catalyst 60. Most common causes of premature failure of the SCR catalyst 60 are typically either a result of the ingress of damaged pump parts being accidentally transferred into the AdBlue tank or as a result of incorrect material selection. Inert materials should thus always be used to handle AdBlue.

Thus, poor quality of AdBlue can cause increased vehicle pollution and also damage to engine exhaust gas systems. It is not always possible for vehicle drivers to be certain about the origin of AdBlue, DEF that is utilized in their vehicles, and can in consequence unintentionally cause, for example, dangerous pollution from contaminants present in the AdBlue, DEF. However, devices for metering concentrations of urea solution are known, for example a device as described in published United States patent application US 2005/001183A1 (Ripper et al.). The device includes a sensor unit for monitoring one or more physical state variables of an

enzyme-free urea solution. The sensor unit is designed for detecting pH, a dielectric constant of the urea solution and/or conduction of the enzyme-free urea solution. Electrodes of the sensor unit are, for example, implemented as an intermeshed comb-like structure. Moreover, the sensor unit includes a vibration generator for testing mechanical properties of the urea solution, wherein the vibration generator includes a quartz oscillator and/or a piezoelectric crystal. It is to be appreciated that the device described in published United States patent application US 2005/0011183A1 (Ripper et al.) is essentially a urea solution concentration measuring device, which is very different to a urea solution quality measuring apparatus.

However, such known devices for metering urea solution concentration are not sensitive enough and/or accurate enough for distinguishing between various qualities of urea solution for vehicle use, for example distinguishing agricultural-grade urea from transport-grade urea due to presence of trace metal salts that hardly cause any perceptible change in urea solution concentration. Urea solution quality spatially varies within a vehicle urea tank and known sensors measure in a given spatial locality which is potentially not representative of the generally quality of the urea solution in the tank; thus, the aforementioned device described in published United States patent application US 2005/0011183A1 (Ripper et al.) would be unsuitable for constructing a urea quality monitoring apparatus.

SUMMARY OF THE INVENTION

The present invention seeks to provide a quality sensor apparatus which is operable to distinguish more accurately between various qualities of urea solution within a urea tank.

According to a first aspect of the present invention, there is provided an apparatus as claimed in appended claim 1: there is provided an apparatus for measuring quality of a urea solution into which at least a portion of the apparatus is inserted in operation,

characterized in that

the apparatus includes a configuration of sensors for measuring mechanical and electrical properties within a volume of the urea solution, the measurements of mechanical and electrical properties being mutually differently influenced by components present in the urea solution, and

a data processing arrangement for processing the measurements of mechanical and electrical properties for generating output data indicative of a quality of the urea solution.

The invention is of advantage in that the quality of the urea solution is susceptible to being measured with greater accuracy and reliability.

Optionally, in the apparatus, the configuration of sensors includes acoustic and conductivity sensors for measuring mechanical and electrical properties respectively, the sensors being spatially deployed spaced apart within the apparatus.

Optionally, in the apparatus, the sensors include a thermometer for measuring a temperature (T) of the urea solution, and for providing the data processing arrangement data corresponding to the temperature (T) for use in computing the quality of the urea solution.

Optionally, in the apparatus, the configuration of sensors includes an electrical conductivity sensor for measuring an electrical conductivity of the urea solution, the conductivity sensor including a configuration of electrodes disposed in a flow tunnel for receiving the urea solution, the flow tunnel being operable to electrically screen the configuration of electrodes from external influences spatially outside the tunnel. More optionally, in the apparatus, the configuration of elec-

trodes includes electrodes disposed in a linear arrangement along the flow tunnel. More optionally, in the apparatus, an outer set of electrodes (P₁) near ends of the flow tunnel are operable to be excited to generate an interrogating electric field within the tunnel and an inner set of electrodes (P₂) near a central region of the flow tunnel are operable to generate a received signal for conveying to the data processing arrangement. Optionally, in the apparatus, the configuration of electrodes (P₁, P₂) includes at least one of: stainless steel electrodes, carbon electrodes, silver electrodes. Optionally, in the apparatus, the data processing arrangement is operable to apply at least one of alternating (a.c.) signals and static (d.c.) signals to the configuration of electrodes when in operation for determining at least one of static conductivity and complex conductivity of the urea solution for use in determining its quality.

Optionally, in the apparatus, the configuration of sensors includes an acoustic sensor including an acoustic transducer arrangement disposed in a spaced apart manner from a corresponding acoustic reflector, wherein the transducer arrangement is operable to generate one or more acoustic pulses which propagate through the urea solution, are reflected from the reflector and are subsequently received back at the transducer arrangement for generating a received signal for the data processing arrangement to process for determining a density of the urea solution.

Optionally, the apparatus further includes a mounting flange for mounting the apparatus to a urea solution tank, a heater arrangement for heating the urea solution, and a urea solution level sensing arrangement for sensing a surface height of the urea solution relative to the apparatus.

According to a second aspect of the invention, there is provided a method of measuring a quality of a urea solution by using an apparatus, characterized in that the method includes:

- (a) arranging for at least a portion of the apparatus to be inserted in operation into the urea solution;
- (b) measuring using a configuration of sensors of the apparatus for measuring mechanical and electrical properties within a volume of the urea solution, the measurements of mechanical and electrical properties being mutually differently influenced by components present in the urea solution; and
- (c) processing using a data processing arrangement the measurements of mechanical and electrical properties for generating output data indicative of a quality of the urea solution.

According to a third aspect of the invention, there is provided a software product recorded on a machine readable medium, the software product being executable on computing hardware for implementing a method pursuant to the second aspect of the invention.

According to a fourth aspect of the invention, there is provided an apparatus for measuring quality of a solution into which at least a portion of the apparatus is inserted in operation,

characterized in that

the apparatus includes a configuration of sensors for measuring mechanical and electrical properties within a volume of the solution, the measurements of mechanical and electrical properties being mutually differently influenced by components present in the solution, and

a data processing arrangement for processing the measurement of mechanical and electrical properties for generating output data indicative of a quality of the solution.

According to a fifth aspect of the invention, there is provided a method of measuring a quality of a solution by using an apparatus, characterized in that the method includes:

- (a) arranging for at least a portion of the apparatus to be inserted in operation into the solution;
- (b) measuring using a configuration of sensors of the apparatus for measuring mechanical and electrical properties within a volume of the solution, the measurements of mechanical and electrical properties being mutually differently influenced by components present in the solution; and
- (c) processing using a data processing arrangement the measurements of mechanical and electrical properties for generating output data indicative of a quality of the solution.

It will be appreciated that features of the invention are susceptible to being combined in various combinations without departing from the scope of the invention.

DESCRIPTION OF THE DIAGRAMS

Embodiments of the present invention will now be described, by way of example only, with reference to the following diagrams wherein:

FIG. 1 is a schematic illustration of an exhaust system of a vehicle operable to employ AdBlue (“Adblue”), namely urea solution, for reducing NOx concentrations in exhaust gases passing through the exhaust system;

FIG. 2A to FIG. 2C are schematic illustrations of embodiments of a quality sensor apparatus pursuant to the present invention;

FIG. 3 is a schematic illustration of density characteristics of a urea solution;

FIG. 4 is a schematic illustration of conductivity measurements of a urea solution;

FIG. 5 is a schematic illustration of an acoustic sensor of the apparatus of FIG. 2;

FIG. 6 is a schematic illustration of a conductivity sensor of the apparatus of FIG. 2A to 2C; and

FIG. 7 is a circuit configuration for use with the conductivity sensor of FIG. 6.

In the accompanying diagrams, an underlined number is employed to represent an item over which the underlined number is positioned or an item to which the underlined number is adjacent. A non-underlined number relates to an item identified by a line linking the non-underlined number to the item. When a number is non-underlined and accompanied by an associated arrow, the non-underlined number is used to identify a general item at which the arrow is pointing.

DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The preset invention is concerned with providing a quality sensor apparatus for measuring solution quality within a representative spatial region of the solution, for example a urea solution present within a storage tank, by using a spatially distributed combination of sensors integrated to an apparatus assembly; the apparatus is operable to measure solution characteristics within an extensive volume of the solution. Such an apparatus is in contradistinction to known devices for measuring urea solution concentration characteristics by implementing a measurement at a specific spatial point within a tank containing urea solution in operation. Beneficially, measurement of urea solution quality is achieved by determining a velocity of acoustic radiation propagating within an extensive spatial volume of the solution, most advantageously utilizing reflected acoustic radiation to increase an

effective propagation path length. Moreover, measurement of electrical conductivity of urea solution is beneficially implemented using a configuration of electrodes in an extensive spatial configuration providing enhanced measurement accuracy through a significance spatial region of the solution. Optionally, alternating current (a.c.) measurements are performed to assist to characterize quality-indicative properties of the urea solution. More optionally, such a.c. measurements are performed at frequencies corresponding to dipole moments of ions present in solution, thereby enabling the nature of the ions to be determined and hence an indication of types of impurities present in the solution. Optionally, direct current (d.c.) measurements are performed to assist to characterize quality-indicative properties of the urea solution. Optionally, combinations of a.c. and d.c. measurements are utilized for measuring the quality of the solution. Both urea solution density and urea solution electrical conductivity are a function of urea solution temperature which is also monitored in the quality sensor apparatus. Density and electrical conductivity measurements of a urea solution, optionally as a function of temperature, are employed as input parameters to a mapping function whose output parameter is an indication of quality of the urea solution; such an indication of quality should not be confused with concentration measurement which is another issue. The mapping function is beneficially implemented using one or more software products stored on machine-readable media, the products being executable on computing hardware of the apparatus to provide the mapping function. Moreover, the mapping function is optionally implemented as a lookup table, an interpolated polynomial representation and/or as a mathematical model embodying formulae representing measurement processes utilized in the apparatus. Optionally, the mapping function is implemented as a neural-network type function implemented in software.

Implementations of the apparatus will now be described with reference to FIG. 2A, FIG. 2B and FIG. 2C. In FIG. 2A, the apparatus is indicated generally by **100** and comprises a flange **110** including an electrical connector **120** for receiving power and providing input and output signals to and from the apparatus **100** respectively. Moreover, the apparatus **100** includes pipe connections **130** for receiving hoses for heating water for heating a urea solution into which a heating coil or heating loop **140** of the apparatus **100** is at least partially immersed in operation. The flange **110** is adapted for enabling the apparatus **100** to be mounted to a hole provided in a urea solution tank (not shown). Optionally, the tank is mounted on a road vehicle, wherein the tank is operable to store urea solution to be injected into an exhaust system of the vehicle for treating NOx combustion products generated in operation by a combustion engine of the vehicle. The flange **110** is further provided with one or more tube connections and associated tubes denoted by **240** through the flange **110** for adding, removing and/or recirculating urea solution, as well as providing venting.

The apparatus **100** further comprises a urea solution level meter comprising a sensor tube **150** provided with an associated float **160**. The float **160** is operable to float on an upper surface of a volume of urea solution. Moreover, the float **160** includes one or more permanent magnets, and the sensor tube **150** includes a spatial series of magnetic reed relays disposed therealong which are selectively actuated in operation in response to the float **160** moving along the sensor tube **150** as denoted by an arrow **170**. Additionally, the apparatus **100** includes one or more temperature sensors **180A**, **180B**, for example implemented as a thermocouple and/or a thermistor. The temperature sensor **180A** is beneficially in close spatial

proximity to sensors **190**, **200** of the apparatus **110**, and the temperature sensor **180B** is beneficially mounted onto the sensor tube **150**.

At a lower end of the heating coil or heating loop **140** are mounted an acoustic sensor **190** for measuring density of the urea solution, and also an electrical conductivity sensor **200**. In FIG. 2B, the sensors **190**, **200** are positioned at a distal end of an extensive "L" heating loop **140**. The acoustic sensor **190** and the conductivity sensor **200** are spatially separate, optionally disposed in an adjacent butting configuration, and are operable to characterize a urea solution by measuring within a significant portion of a volume of the urea solution tank in contradistinction to contemporary urea solution measuring devices which perform a measurement at only a spatial point locality. Output signals from the sensors **180A**, **180B**, **190**, **200** are conveyed via signal cables **210**, **220** to a data processing unit **230** including computing hardware, for example a microcontroller, operable to execute one or more software products stored on machine readable media, for example solid state read/write data memory, for enabling the computing hardware to process the output signals conveyed via the cables **210**, **220** to generate a measurement output available at the electrical connector **120**. In FIG. 2C, the heating loop **140** is implemented as a spiral structure comprising one or more turns; a spiral is potentially more compact and provides a greater heating surface area, thereby more rapid heating of the urea solution. Conversely, an extensive L-loop implementation of FIG. 2B provides heating in a larger spatial volume.

As described briefly in the foregoing, the density ρ and electrical conductivity S of a urea solution is describable in general terms from Equations 1 and 2 (Eq.1 and Eq. 2):

$$\rho = F_1(T, K, q) \quad \text{Eq. 1}$$

$$S = F_2(T, K, q) \quad \text{Eq. 2}$$

wherein

T=temperature;

K=concentration of urea in solution in a tank;

q=concentration of impurities present in the tank;

F₁=first function providing density as an output;

F₂=second function providing electrical conductivity as an output.

Referring to FIG. 3, there is shown in qualitative manner, in a graph indicated generally by **300** and including an abscissa axis **320** denoting increasing temperature from left to right and an ordinate axis **310** denoting increasing density from bottom to top, a variation of the density ρ as a function of the different concentrations of urea K and temperature T of the urea solution. Below a transition temperature T_F, urea freezes out of the solution and the volume of the frozen solution expands. Above the transition temperature T_F, the urea solution exhibits properties which become more akin to plain water. A concentration K₁ corresponds to a greater concentration of urea in water in comparison to a concentration K₂; similarly, the concentration K₂ corresponds to a greater concentration of urea in water in comparison to a concentration K₃. The density ρ is sensed in the apparatus **100** by measuring a propagation delay of a pulse burst of ultrasonic radiation through the urea solution in the tank; for a given propagation path of length L within the urea solution in the tank, the propagation delay Δt is inversely proportional to acoustic velocity v of the acoustic pulse, namely as defined by Equation 3 (Eq. 3):

$$\Delta t = \frac{L}{v} \quad \text{Eq. 3}$$

Beneficially, on account of a relatively compact nature of the apparatus **100**, in order to include enough oscillations to define a pulse precisely within a Fourier domain, the pulse burst preferably includes a few cycles of acoustic radiation having a frequency in a range of 300 kHz to 10 MHz, more preferably in a range 700 kHz to 3 MHz, and most preferably substantially 1 MHz. In an event that a single pulse is utilized, its pulse length is thus beneficially in an order of 1 μ sec duration. Knowing the temperature T and the propagation delay Δt , the density ρ can be computed from Equation 4 (Eq. 4):

$$\rho = F_3(R, \Delta t) \quad \text{Eq. 4}$$

A combination of Equations 3, 4 and 1 can be used to determine a combined contribution of the concentration of urea K and an indication of the impurities q. These functions can be derived from theoretical analysis or determined numerically, for example as a lookup table with interpolation or as a polynomial representation, from experimental results from various known calibration urea solutions.

The speed of sound in a non-gaseous medium takes into account non-zero stiffness both for volumetric and shear deformations. It is thus feasible to generate sound waves with different velocities depending upon which deformation mode is utilized. Sound waves generating volumetric deformations, namely compressions, and shear deformations are referred to as longitudinal and shear waves respectively. In Earthquakes, corresponding seismic waves are referred to as P-waves and S-waves respectively. The sound velocities of these two types of waves are provided in Equations 5 and 6 (Eq. 5 & Eq. 6):

$$c_p = \sqrt{\frac{K_B + \frac{4}{3}G}{\rho}} = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \quad \text{Eq. 5}$$

$$c_s = \sqrt{\frac{G}{\rho}} \quad \text{Eq. 6}$$

wherein

K_B and G are bulk modulus and shear modulus of the urea solution respectively;

c_p=velocity of volumetric wave;

c_s=velocity of shear wave;

E=Young's modulus; and

ν =Poisson's ratio.

It will be appreciated that density of the urea solution is not sufficient in itself to characterize the quality of the urea solution when other contaminants are also present, for example metallic salts. Such metallic salts can represent a pollution hazard when ejected from an exhaust system of a vehicle and can also result in catalyst poisoning in vehicle exhaust systems. Such catalysts can include noble metals which are expensive to replace. It is therefore important to identify when an inferior grade of Adblue, DEF has been employed which could risk damaging by poisoning catalytic components of a vehicle exhaust treatment system.

Although the acoustic sensor **190** is susceptible to being used to determine urea solution density ρ via sound velocity measurement, such measurement is not sufficient in itself to determine a presence of other trace contaminants which may also be present in the urea solution, for example diverse metal

salts. In order to obtain further information regarding these other trace contaminants, the conductivity sensor **200** is employed by the apparatus **100**. Conductivity of a urea solution generally increases with temperature T because increasing temperature T causes more dissociation between ions within the urea solution as illustrated in FIG. **4**; in FIG. **4**, there is shown a graph indicated generally by **400** including an abscissa axis **420** denoting increasing temperature T from left to right and an ordinate axis **410** denoting increasing conductivity S from bottom to top. Moreover, the electrical conductivity S of a urea solution is also determined by a concentration of urea in the solution as well as impurities such as metallic salts present in the solution. A given concentration of urea solution at a given temperature should have a corresponding density ρ and a corresponding electrical conductivity S ; when such density ρ and conductivity S as a function of temperature T deviate from what is expected, such deviation is indicative of the presence of contamination q .

The conductivity S is susceptible to being measured using alternating signals (a.c.), for example via capacitive coupling. Optionally, direct current (d.c.) signals can be employed, either alone or in combination with applied a.c. signals. Depending upon a nature of electrodes used to make contact with the urea solution, either an ohmic or electropotential (junction) contact is made to the urea solution. For example, carbon and silver electrodes are capable of making an ohmic contact to the solution, whereas metals such as stainless steel are observed to make an electropotential contact with the solution. Whereas ohmic contacts result in a constant resistance as a function of a potential difference between test electrodes to measure conductivity of a urea solution, electropotential contacts result in a varying resistance as a function of the potential difference applied between the electrodes. This varying resistance as a function of potential difference is influenced by trace metal salt contaminants present in the urea solution and can optionally be used to determine a concentration of trace salts present in the urea solution, namely to derive an indication of the quality of the urea solution. When a.c. signals are employed to measure conductivity of the urea solution and relatively high electrode potential are used which greatly exceed any electropotential (junction) contact, the influence of such an electropotential (junction) becomes less significant.

Conductivity of a urea solution using alternating signals (a.c.) concerns complex impedances which vary as a function of frequency. Optionally, a.c. measurement of conductivity is performed in the apparatus at a frequency in a range of 100 Hz to 10 kHz, for beneficially substantially 5 kHz which is convenient for low-power electronic circuits to process. For example, an a.c. frequency of 5.1 kHz is conveniently employed. When a frequency of the alternating signals is in a regime of 100 kHz to 10 MHz, ionic dipole moments in the urea solution become significant and are clearly detectable in measured complex impedance as a function of temperature. Such complex impedances have been reported in an academic paper "Frequency dependence of ionic conductivity of electrolyte solutions", Chandra & Bagchi in association with research supported by the Council of Scientific and Industrial Research (CSIR), Department of Science and Technology (DST), and Government of India and Indian National Science Academy. This document is in the public domain and its contents are hereby incorporated by reference. The complex impedance of the urea solution is also influenced by contaminants such as metallic salts present in the solution.

Thus, the apparatus **100** via the conductivity sensor **200** is operable to measure d.c. conductivity and/or a.c. conductivity

of the urea solution in the tank as a function of temperature T as denoted by Equation 2 (Eq. 2) in the foregoing:

$$S = F_2(T, K, q) \quad \text{Eq. 2}$$

wherein

K = concentration of urea solution;

T = temperature of the urea solution; and

q = concentration of impurities present in the tank.

As aforementioned, Equations 1 and 2 represent two simultaneous equations with two unknown factors concentration K and impurity q contributing to conductivity S and density ρ , which enables these unknown factors to be computed. Measurement of the conductivity at a.c. frequencies and/or determination of conductivity with electrodes giving rise to electropotential measurements enables further simultaneous equations to be established, enabling factor K and q to be more accurately determined. Both impurity q and concentration K enable the overall quality and suitability for use of the urea solution in the tank to be monitored. The simultaneous equations are beneficially solved by at least one of: lookup tables, polynomial representations.

The acoustic sensor **190** and the conductivity sensor **200** will now be described in more detail with reference to FIG. **5** and FIG. **6** respectively. In FIG. **5**, the acoustic sensor **190** includes an elongate support panel **500** bearing an acoustic reflector **510** substantially at a first end of the panel **500**. At a second end of the panel **500**, remote from the first end, there is included a transducer arrangement comprising a housing **520** having an opening directed away from the reflector **510** as illustrated. The transducer arrangement further includes a piezo-electric element **530** implemented as a ceramic material disc, a quartz material disc and/or an organic polymer material disc. The element **530** is coupled to the urea solution in operation via the housing **520**. Optionally, the housing **520** is fabricated from metal, a robust polymeric material, for example polyurethane, PTFE or similar, or from a ceramic material. Moreover, the element **530** is sealed and protected within the housing **520** by a region of chemically inert acoustic-energy-absorbing material **550**, for example implemented as an appropriate grade of epoxy resin or other polymeric material. In operation, a pulse signal is applied via one or more electrodes S_D to the element **530** to generate of an outward acoustic pulse series **600** which propagates along an elongate axis of the panel **500** to impinge upon the reflector **510** and to be then subsequently reflected therefrom as a reflected acoustic pulse series **610** which propagates back to the transducer arrangement to generate an echo signal in at the one or more electrodes S_D . Optionally, the element **530** is furnished with at least a pair of electrodes; a potential difference applied between the pair of electrodes establishes an electric field in the element **530**, thereby causing stress which results in strain deformation of the element **530** and generation of associated acoustic radiation; a stress applied to the element **530** is also capable of generating an electric field within the element **530** which is detectable as a potential difference across the pair of electrodes. More optionally, the element **530** is furnished with separate electrodes for receiving drive signals and for outputting received echo signals. The data processing unit **230** is operable to generate a drive signal for the one or more electrodes S_D and to receive reflected signals for processing. The acoustic sensor **190** is required to provide many years of reliable service when in contact with urea solution which can be corrosive. It is thus to be appreciated that the acoustic sensor **190** is not a simple assembly to design, and materials used for its construction have been selected with great care and attention to achieve reliable performance over many years of use. For example, stresses are

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reduced within the acoustic sensor **190** which could otherwise result in cracking of the element **530**; such reduction in stress is feasible, for example, by employing laterally slidable surfaces for interfacing onto the element **530**.

The conductivity sensor **200** is shown in greater detail in FIG. **6** and includes an elongate tunnel housing **700** fabricated from insulating plastics material with open ends for receiving a flow of urea solution through the housing **700** as denoted by arrows for a first flow direction; flow through the housing **700** can also occur in operation in an direction opposite to that shown. Moreover, the housing **700** is mounted onto a base **710** also fabricated from insulating plastics material. Along the base **710** are disposed a series of four electrodes **720** denoted by P_1 for outer electrodes and P_2 for inner electrodes. Optionally, the electrodes **720** are implemented using stainless steel material.

In operation, when performing a.c. measurement of the conductivity S , an a.c. energizing signal current I_B from a modulated current source established by the data processing unit **230** across the electrodes P_1 to generate an electric field along the housing **700** which is detected by the electrodes P_2 as a potential difference V_A , the electrodes P_2 being coupled via resistors R_1, R_2 to an operational amplifier **800** to generate a differential signal S_E which is coupled to an analogue sampling input of the data processing unit **230**. As the conductivity of the urea solution in the housing **700** varies, current flowing between the electrodes P_1 as a result of the bias current I_B follows a spatial distribution within the housing **700** which is modulated as a function of the conductivity of the urea solution which influences the differential signal accordingly. Thus, the signal S_E is a monotonic representation of the concentration K of urea in the urea solution. The data processing unit **230** is operable to receive the signal S_E to convert it to data, and then to use this data to determining conductivity of the urea solution and hence a measure of its quality.

Optionally, the bias current I_B optionally includes an a.c. signal component and/or is an a.c. signal. Moreover, the a.c. signal component and/or a.c. signal induces an alternating electric field within the housing **700** which interacts with dipole moments of ions in the urea solution. In consequence, the potential difference V_A is an alternating signal which is amplified by the amplifier **800** and which is then subject to synchronous demodulation within the data processing unit **230** for determining a complex impedance for the urea solution. Beneficially, such synchronous demodulation is synchronized to a waveform applied to the electrodes P_1 to generate in-phase and quadrature signal components from the potential difference V_A whose relative magnitudes are susceptible to being used within the data processing unit **230** for more accurately determining the magnitude of the impurities q . Such a.c. measurement of conductivity S of the urea solution provides insight with regard to impurities, for example metal salts, present in the urea solution as elucidated in the foregoing. Optionally, the sensors **190, 200** are operated temporally alternately to avoid signal cross-talk therebetween, thereby improving measuring accuracy of the apparatus **100**.

The apparatus **100** is distinguished from previous manners of measuring urea solution characteristics on account of an high measurement accuracy, high robustness and great ease of use of the apparatus. On account of providing a measurement over a larger spatial volume, the apparatus **100** is operable to provide a more representative indication of urea solution quality in comparison to earlier approaches. The apparatus **100** is capable of being used to measure qualities of both enzyme-containing urea solution as well as enzyme-free urea solution. Optionally, the apparatus **100** is capable of

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being adapted to measure qualities of other type of solution in addition, or as an alternative to, quality of urea solution

Thus, although the apparatus **100** in the foregoing is described in relation to measuring quality of urea solution in relation to road vehicles, off-road vehicles, in industrial applications such as stationary generator sets, in aircraft and in marine applications, the apparatus **100** is susceptible to being adapted to measure other types of solution and their associated quality characteristics, for example in oil industries, chemical processing industries, in food processing industries, in pharmaceutical industries, in water treatment industries, in fish cultivation industries, and so forth. In order to address such industries, complex impedance measurements executed by the data processing unit **230** in cooperation with the conductivity sensor **200** are a useful asset. Optionally, the apparatus **100** is furnished with other types of chemical sensors, for example electrochemical sensors and/or optical sensors, for example coupled to the data processing unit **230**, for undertaking more complex solution quality monitoring tasks.

The data processing unit **230** is operable to perform a mapping function between signals that it receives from its sensors **180, 190, 200** and output that it provides indicative of quality of a solution into which the apparatus **100** is at least partially inserted. The mapping function is beneficially implemented in the data processing unit **230** via one or more executable software products recorded on data media, for example in solid state data memory. The software products are operable to provide the mapping function:

- (a) by way of a lookup table;
- (b) by way of one or more polynomial functions whose coefficients are recorded in the data memory; and/or
- (c) by way of a neural network mapping function.

For example, complex impedance measurement using the sensor **200** over a frequency range from 100 kHz to 10 MHz generates a complex sequence of impedance measurements a function of frequency. Potentially, a given impurity ion resulting from a metallic salt present in the urea solution can influence the complex impedance at several spot frequencies in the frequency range. Interpreting the complex impedance can be convoluted especially when there is noise present due to movement of a vehicle with which the apparatus **100** is installed. By using the complex impedance measurement at various spot frequencies as input to a neural network algorithm, the algorithm can be adapted to recognize different types of urea solution and their associated qualities. Beneficially, the algorithm is also furnished with data from one or more of the sensors **180A, 180B, 190**. Parameters employed in the data processing unit **230** for performing the aforementioned mapping are beneficially dynamically alterable by data instructions sent to the data processing unit **230**. Such alterable functionality enables the apparatus **100** to be dynamically updated with parameters which enable it to most accurately identify various types of impurity. For example, in an agricultural environment, there may be a spate of cases where specific types of impure low-grade urea are used for Adblue, DEF to save money, but which cause unexpected environmental damage by way of engine emissions via their exhaust treatment systems. The apparatus **100** beneficially needs to be adaptable to identify most effectively such spates of abuse. Optionally, operating parameters of the apparatus **100** can be updated by supplying external data to the data processing unit **230** for enabling the apparatus **100** to adapt dynamically to different types of solution.

When the apparatus **100** is mounted to a tank of a vehicle, movement of the vehicle in operation influences liquid in the tank, for example causing it to slosh around the tank and thereby resulting in measurements executed by the sensors

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190, 200 to be temporally varying. In consequence, the apparatus 100 is optionally operable to average its measurements over a period of time. Optionally, the period of time over which averaging occurs is dynamically variable in response to data instructions sent to the data processing unit 230 of the apparatus 100.

Modifications to embodiments of the invention described in the foregoing are possible without departing from the scope of the invention as defined by the accompanying claims. Expressions such as “including”, “comprising”, “incorporating”, “consisting of”, “have”, “is” used to describe and claim the present invention are intended to be construed in a non-exclusive manner, namely allowing for items, components or elements not explicitly described also to be present. Reference to the singular is also to be construed to relate to the plural. Numerals included within parentheses in the accompanying claims are intended to assist understanding of the claims and should not be construed in any way to limit subject matter claimed by these claims.

The invention claimed is:

1. An apparatus (100) for measuring the quality of a urea solution in a tank, wherein at least a portion of said apparatus is inserted in said tank, the apparatus comprising,

a configuration of sensors (180, 190, 200), wherein said sensors (180, 190, 200) are spatially distributed for measuring mechanical and electrical properties within a volume of said urea solution, said measurements of mechanical and electrical properties being influenced by components present in the urea solution which influence the quality of the urea solution, and

a data processing arrangement (230) for processing said measurements of said mechanical and electrical properties for generating output data (120) indicative of the quality of said urea solution.

2. An apparatus (100) as claimed in claim 1, wherein said configuration of sensors (180, 190, 200) includes acoustic and conductivity sensors (190, 200) for measuring mechanical and electrical properties respectively, said sensors (190, 200) being spatially deployed spaced apart within said apparatus (100).

3. An apparatus (100) as claimed in claim 1, wherein said sensors (180, 190, 200) include a thermometer for measuring a temperature (T) of said urea solution, and for providing said data processing arrangement (230) data corresponding to said temperature (T) for use in computing said quality of said urea solution.

4. An apparatus (100) as claimed in claim 2, wherein said sensors (180, 190, 200) include a thermometer for measuring a temperature (T) of said urea solution, and for providing said data processing arrangement (230) data corresponding to said temperature (T) for use in computing said quality of said urea solution.

5. An apparatus (100) for measuring the quality of a urea solution in a tank, wherein at least a portion of said apparatus is inserted in said tank the apparatus comprising,

a configuration of sensors (180, 190, 200), wherein said sensors (180, 190, 200) are spatially distributed for measuring mechanical and electrical properties within a volume of said urea solution, said measurements of mechanical and electrical properties being influenced by components present in the urea solution which influence the quality of the urea solution, and

wherein said configuration of sensors (180, 190, 200) includes an electrical conductivity sensor for measuring an electrical conductivity of the urea solution, said conductivity sensor including a configuration of electrodes (720) disposed in a flow tunnel (700, 710) for receiving

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the urea solution, said flow tunnel (700, 710) being operable to electrically screen said configuration of electrodes from external influences spatially outside said tunnel (700, 710), and

a data processing arrangement (230) for processing said measurements of said mechanical and electrical properties for generating output data (120) indicative of the quality of said urea solution.

6. An apparatus (100) as claimed in claim 5, wherein said configuration of electrodes (720) includes electrodes disposed in a linear arrangement along said flow tunnel (700, 710).

7. An apparatus (100) as claimed in claim 6, wherein an outer set of electrodes (P1) near ends of the flow tunnel (700, 710) are operable to be excited to generate an interrogating electric field within said tunnel (700, 710) and an inner set of electrodes (P2) near a central region of the flow tunnel (700, 710) are operable to generate a received signal for conveying to the data processing arrangement (230).

8. An apparatus (100) as claimed in claim 5, wherein said configuration of electrodes (P1, P2) includes at least one of: stainless steel electrodes, carbon electrodes, silver electrodes.

9. An apparatus (100) as claimed in claim 6, wherein said configuration of electrodes (P1, P2) includes at least one of: stainless steel electrodes, carbon electrodes, silver electrodes.

10. An apparatus (100) as claimed in claim 7, wherein said configuration of electrodes (P1, P2) includes at least one of: stainless steel electrodes, carbon electrodes, silver electrodes.

11. An apparatus (100) as claimed in claim 1, wherein said data processing arrangement (230) is operable to apply at least one of alternating (a.c.) signals and static (d.c.) signals to said configuration of electrodes (720) when in operation for determining at least one of static conductivity and complex conductivity of said urea solution for use in determining its quality.

12. An apparatus (100) as claimed in claim 1, wherein said configuration of sensors (180, 190, 200) includes an acoustic sensor (180) including an acoustic transducer arrangement (530) disposed in a spaced apart manner from a corresponding acoustic reflector (510), wherein the transducer arrangement (530) is operable to generate one or more acoustic pulses which propagate through the urea solution, are reflected from the reflector (510) and are subsequently received back at the transducer arrangement (530) for generating a received signal for the data processing arrangement (230) to process for determining a density of the urea solution.

13. An apparatus (100) as claimed in claim 1, wherein said apparatus (100) further includes a mounting flange (110) for mounting said apparatus (100) to a urea solution tank, a heater arrangement (130, 140) for heating said urea solution, and a urea solution level sensing arrangement (150, 160) for sensing a surface height of the urea solution relative to said apparatus (100).

14. A method of measuring the quality of a urea solution by using an apparatus (100), said method comprising:

(a) inserting at least a portion of said apparatus into said urea solution;

(b) measuring using a configuration of sensors (180, 190, 200) of said apparatus (100), wherein said sensors (180, 190, 200) are spatially distributed for measuring mechanical and electrical properties within a volume of said urea solution, said measurements of mechanical and electrical properties being influenced by components present in the urea solution which influence the quality of the urea solution; and

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(c) processing using a data processing arrangement (**230**)
said measurements of said mechanical and electrical
properties for generating output data (**120**) indicative of
the quality of said urea solution.

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